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SOUTHEASTERN GEOLOGY

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1962

BOUGUER GRAVITY MAP OF NORTH CAROLINA

by

Virgil I. Mann
University of North Carolina

ABSTRACT

A Bouguer gravity map of North Carolina (d = 2.67) is presented from the data collected from 4,000 gravity stations in the State. In the Piedmont and Mountain portions of the State, some correlation between Bouguer values and rock types may be readily observed; however in the Coastal Plain, important Bouguer changes appear to be caused by subsurface rock variations. The general pattern for the State of North Carolina shows strong negative values in both the east and west portions, with a persistent positive zone in the central Piedmont. Local variations from this general Bouguer pattern are discussed briefly for each physiographic province.

INTRODUCTION

In 1957 a study of the earth's gravitational field in North Carolina was undertaken at the University of North Carolina at Chapel Hill. This has culminated in the current presentation of the Bouguer Gravity Map of North Carolina.

During the early phases of the project, stations were established with gravity meters loaned by the Geophysics Division of the Geology Department of the University of Wisconsin. In 1958 the University of North Carolina purchased its own meter, and the remaining stations were established with it. Enough cross checks were made to assure that values obtained by the various meters were comparable.

Except for numerous field checks, the original 4,000 stations were established by December, 1960. After the data was examined, a number of stations were recalculated in the laboratory, and rechecked in the field. Such cross checking has caused modifications of values in some portions of the map, but has not altered the gross features. I have no doubt that there may be some further modifications of the map made at a later date as more stations are collected; but as of now the map and the data from which it is drawn are as completely cross checked as is possible.

Acknowledgements

This project was undertaken with the encouragement of George P. Woollard of the University of Wisconsin. Dr. Woollard not only loaned meters to the project, but his staff completed the gravity computations, and returned the results to us on I. B. M. forms. The project was paid for by National Science Foundation Grant No. G-5042, and transportation and laboratory facilities were made available by the University of North Carolina. Those U. N. C. graduate students who contributed most to the project include Frank S. Zablocki, Lee Fournier, Ralph Guidroz, Floyd Ackerman, Ben Morgan, and Dale Glover. Each established some stations used in the final map, and did some of the preliminary computation. Special appreciation is expressed to G. R. MacCarthy for critically reading the manuscript.

COLLECTION OF THE GRAVITY DATA

Field Techniques

The original plan of locating a gravity station every 10 miles was carried out as far as possible. A crude grid was superimposed upon the map of North Carolina, and stations were selected arbitrarily so that no station was more than 10 miles away from the adjoining stations. As field work progressed modifications of this plan were made necessary by obstacles such as, 1) lack of roads, 2) no bench marks, 3) closed Armed Service and government installations, as well as, 4) newly flooded areas which made some regions inacessible. Even so, I believe we have a station coverage very close to that of our original plan.

In order to establish a known base station for the project, in 1956 George P. Woollard tied the Chapel Hill station to the Washington, D. C. station at the Commerce Building, thus giving Chapel Hill a station, of observed "g" whose value is: 979.8182 gals. The following year a grid of stations was set by Mann through the State, and all other future stations were tried into this grid. It is my belief that absolute values have been obtained for all observed stations. In the near future, the Principal Facts for many of these stations will be published.

Three Worden gravity meters were used to collect the data. Worden #10 located the Chapel Hill Base station; Worden #14 established the skeleton grid; and Worden #121 was used to locate the nearly 3,500 other stations. Whereas Worden #10, and Worden #14 are geodetic instruments, Worden #121 is not. It has a sensitivity of 0.3187 milligals per scale division, and hence had to be reset carefully. Drift of all meters was slow and regular, and instrument problems were minor. Cross checks between these three meters were consistent and satisfactory.

Elevation of the stations was obtained either at bench marks or by a Paulin altimeter at stations between bench marks. All traverses were tied to bench marks at least once an hour, and most altimeter readings were taken twice on each traverse. Readings were observed at the time the gravity station was taken, and then again on a fast return run. If the two altimeter readings differed by $\pm$ 5 feet for any station, a special traverse was made to obtain the most nearly correct value.

Laboratory Processing

All data received was processed first at the University of North Carolina and then by the University of Wisconsin Geophysics Department. All gravity values were computed as observed "g" values, by applying to each stations the observed base station value for Chapel Hill. The station position was located by latitude and longitude, as well as by a field description. Elevations were determined relative to known bench marks. In some cases where further field checking was believed necessary, the Bouguer value was computed at U.N.C. However, eventually all station values were sent to the University of Wisconsin Geophysics Department for a complete calculation of Theoretical, Free Air, and Bouguer values for various densities.

Each station was first plotted on a base composed of A.M.S series v501 maps. Later, when the U.S.G.S. 1957 map of North Carolina (Scale 1:500,000) became available it was used as a base. In order to maintain agreement with other Bouguer maps published for this area (Woollard, 1939, 1943) and for the United States, (Woollard, 1955) a value of d = 2.67 was chosen to compute the Bouguer values to be plotted; hence this work in its present form could not be tied to the local Coastal area data where Skeels (1950) used d = 1.89. No terrain corrections were made; thus all values are for simple Bouguer.

The contour interval selected for the map was 5 milligals. This interval should be large enough to include all possible errors up to 1 milligal caused by minor mistakes in computation of latitude and elevation without affecting the map in any significant manner. Further, the interval is small enough to outline most of the significant gravity features. From the accuracy of most of the station data a much smaller contour interval could have been used; however, because of the confusion which would be caused by the greater number of contour lines, the five milligal contour interval was chosen. Ten milligal lines (even) are heavy, and are numbered, whereas the 5 milligal lines (odd) are lighter, and are not numbered.

GEOLOGICAL INTERPRETATION OF BOUGUER MAP

A Bouguer gravity map such as this has at least two important functions: 1) it may be used as a portion of a far larger regional gravity field pattern, showing gross structural features (Heiskanen & Vening Meinesz, 1958, Ch. VII; Woollard, 1959) or 2) it may be used to assist in explaining local geologic features (Woollard, 1957). In some areas deep crustal gravity patterns overpower the local features, and the two are difficult to separate (Vajk, 1951). However, in a great many cases as in the Piedmont and Mountain areas of North Carolina, one may correlate rock types with gravity features, and establish a series of gravity patterns which might be used to assist in interpreting geological features. Such was the goal of this work, and it was achieved, in part at least.

In 1958 North Carolina published a new geological map of the State. The map was made chiefly by reconnaissance mapping; however, some local areas have been mapped in detail (Stuckey and Conrad, 1958, p. 8). In order to maintain a reasonably small number of rock names, many rock varieties had to be collected under a common name (Stuckey & Conrad, 1958, p. 9). The Geologic Map of North Carolina (1958) displays such geologic features as rock types, faults, folds, and intrusives on a regional basis, and presents generalized names such as granite to include gneissic granite, orthogneiss, monzonite, granodiorite, and even diorite. This map then is well suited for comparing regional geologic features with the regional gravity features shown on the Bouguer.

Most of the remainder of this paper concerns the interpretation of the Bouguer map in light of the geology. For a complete understanding of this paper, the interested reader should have access to a copy of the 1958 Geology Map of North Carolina. Because a black and white photocopy of the map is most unsatisfactory, and the reprinting of the multicolored map is too expensive, the map is not reproduced with this paper. The reader is invited to make comparisons of Bouguer values directly with the original multicolored North Carolina State Geology Map.

If one viewed a gravity profile along a line from Cape Hatteras to Hot Springs, the Bouguer values would go from a strong negative on the Coast through a wide, high positive in the Piedmont to another strong negative in the Mountains. The strong positive in the Piedmont is related to the slate belt; the strong negative in the west may be related to gneissic and granitic rocks; but the negative along the coast must be related to rocks which are not exposed. Thus the anomalies on the Coastal Plain are doubly interesting for they could represent deep sedimentary basins, changes in rocks which are very deep-seated, or maybe even both. At any rate the anomalies in the Coastal Plain present far more opportunity for speculation for the interested geologist than do most of the anomalies in the Piedmont and in the Mountains.

At this time, no mathematical treatment has been applied to the Bouguer anomalies, other than simple estimates. Profile studies are being made and will be presented later for some of the rock types, to better interpret their depth, shape, and possibly even their origin.

THE COASTAL PLAIN

The Coastal Plain of North Carolina is that portion of the State now covered by sediments no older than Cretaceous; it covers roughly the eastern one-fourth of the State. The western boundary of the area extends southwestward from Roanoke Rapids to Smithfield, thence northwestward to Varina, and then southwestward to Rockingham. For the most part, all exposures south and east of this western boundary are sediments of Cretaceous age, or younger. For purposes of this study, all stations were taken on land areas; hence the eastern boundary for this study is the Outer Banks.

Because of the relatively thin veneer of sediments most large

Bouguer anomalies in the Coastal Plain region cannot be explained by the immediate exposures. Anomalies of twenty to thirty milligals cannot be attributed to thin sedimentary layers on the order of a few thousand feet (Evans & Crompton, 1946); hence the large anomalies found in the Coastal Plain must be interpreted either on the basis of deep subsurface structural, or stratigraphic changes. The solution of gravity anomalies is not unique, and often is ambiguous for they may be caused by many different rock types and arrangements (Romberg, 1958). Even though, in this paper, the anomalies will be interpreted in one way, the interested reader should feel free to interpret them according to the information available to him.

Along the Atlantic Coast there are a number of very interesting anomalies. North of Hatteras, along the coast, is a large negative. The most negative portion appears to lie north of Mann's Harbor, where it has a magnitude of -45 milligals. The large negative suggests a deficiency of mass which could be caused either by a very deep sedimentary basin, or by some other feature far deeper than the underlying Cretaceous sediments. Immediately to the west of this negative is a positive ridge which extends north-south from Hartford to Morehead City. A small nose extends westward to include Vanceboro on the western part of the ridge. The southern part of Pamlico Sound from the latitude of Cape Hatteras to the lattitude of Cape Lookout appears to be roughly a gravity plateau; however, because of the lack of land, only a few stations were taken in this area.

A weak negative lying immediately to the west of the Hartford-Morehead City high appears to be a boundary separating the larger high to the west from the north-south trending ridge. The high which extends from Roanoke Rapids eastward to Winton, and which may be traced as far south as Snow Hill, shows two features. In the northern portion, the high still retains a north-south trend; however, the southern portion displays a northeast-southwest trend. The northeast-southwest trend parallels the high ridge at Vanceboro, and the negative between them decreases from -10 to -20 mg. Thus at the latitude of Cape Hatteras and just south of the Pamlico River-Tar River the first suggestion of an Appalachian trend is exhibited by the gravity values. Eastward from this zone a north-south grain is in evidence, apparently caused by a different set of rocks. Other unexpected trends in the gravity pattern are found to the south of this Snow Hill-Vanceboro area.

South of Kinston three trends are recognizable on the Bouguer map; these are: 1) lineations parallel to the Appalachian trend, 2) northwest-southeast trends normal to the Appalachians, and 3) a grain which is east-west. A positive ridge near Swansboro extends east-west. Proceeding westward from Jacksonville one encounters a rather large mushroom shaped negative. The major axis of the negative described by the -20 mg. contour line is northeast-southwest; however, elongation of the -30 mg. contour line is northwest-southeast. Apparently two different structural trends control this negative anomaly. Further to the south are two more anomalies; a positive north of Maco, and a negative near Southport. Both these anomalies trend east-west.

Although apparently isolated, the large negative centered at Lumberton could well be connected to the large negative near Jacksonville. Because of their sharp gravity boundaries, they both could be caused by the same major structure.

Immediately to the north of a line from Lumberton to Jacksonville, centered around Clinton, is a sharply defined positive. The high values extend roughly along the Appalachian trend nearly to Wilson, with the greatest magnitude between Clinton and Turkey. To the south and to the east of this ridge are negative values. The differential from maximum to minimum suggests a structural disturbance at some depth, perhaps a fault. Small negatives such as those near Mount Olive, and near Goldsboro, could be attributable to local granitic intrusives. Because they are covered, the rocks causing these anomalies cannot be determined with certainty.

To the north of Rocky Mount is a negative which more than likely is caused by granitic intrusives. The larger negative to the west can be directly related to a granite, and there appears to be an association between the two negatives. However, the two negatives trend nearly 90° to one another. If each anomaly outlines an intrusive the major axes of emplacement illustrate two of the trends seen in the subsurface grain of the Coastal Plain.

It is quite possible that the small negative at Varina, and the larger one just north of Fayetteville also are caused by granites. In the area of the Varina anomaly, granites are exposed in windows in the Cretaceous. The writer knows of no such windows in the Fayetteville area; However, the trend exhibited by the granite in Wake County would coincide, if extended, with the axis of this anomaly. To the south of the anomaly near Fayetteville, the negative is cut off by a high which parallels the Appalachian trend.

Thus in the Coastal Plain, three important large structural trends may be recognized on the Bouguer gravity map; a north-south, an east-west, and a northeast-southwest trend. In one place a minor northwest-southeast grain may be seen. All three large features are subsurface trends or lineations. On the other hand there are only two major trends readily apparent in surface features of the region; these are a northeast-southwest direction, and a northwest-southeast grain. The northeast surface lineation agrees with the subsurface, but Cape Fear Arch, a northwest trending feature, coincides in direction with a minor subsurface features. Clearly a careful analysis of this, and other data will be necessary before the proper relationship between these trends is determined.

THE PIEDMONT

In the Piedmont, the anomalies may be related directly to rock exposures. In some cases the rock types can explain the anomaly, and in other cases they cannot.

The first anomaly immediately west of the northern Coastal Plain is a large negative extending from Johnson County northward into Warren County. The minimum gravity values in the anomaly are east of Raleigh, near Wendell, defining a trend which extends roughly northeast-southwest. In Warren County a smaller negative, still within the framework of the larger negative anomaly, extends northward into Virginia. These negatives may be correlated with the large granite mass shown on the State map in this locality, and presumably are caused by it (see Bott, 1956). One should note in passing that the tongue of granite extending southward in Vance County is not an important feature on the Bouguer map. It may not be the same granite, and may have a different origin.

Westward from this negative at Wendell for a distance of approximately sixty miles, and trending northeast-southwest from Virginia to South Carolina, the Bouguer values are positive. This comprises a rather unique positive Bouguer section of the Piedmont.

The central Piedmont is underlain primarily by the volcanic and intrusive rocks of the "slate belt". Bouguer values obtained over these rock types are all positive. The positive values increase to +50 milligals near Graham, in Alamance County, and decrease to zero in the other three directions: on the east near the Jonesboro fault, on the south in Union County, and on the west along a line which runs roughly from Gastonia past Greensboro.

The zero contour on the east trends very roughly parallel to and east of the Jonesboro fault, the eastern border of the Triassic basin. Attempts to interpret rocks within this down faulted block have not been successful from a Bouguer map (Zablocki, 1958). Because of dikes and sills within the Triassic basin, non-typical readings can be obtained by haphazard selections of station locations. To minimize this effect the technique of profiles normal to the trend of the Triassic basin has been used in other places to illustrate, and to interpret, the structure of the basin (Mann and Zablocki, 1961).

If the Bouguer values may be interpreted as being indicative of the thickness of the "slate belt", then the greatest quantity of slate occurs north of Stanley and Montgomery Counties. Locally thick masses of sediments and volcanics will be found near Siler City, Judson Creek, and Beria. The greatest thickness is in Alamance County. The foregoing interpretation is based on an assumption which could be wrong. The validity of this interpretation can only be determined by further detailed studies of rock densities and more detailed field mapping. Fifty milligals seems a very high value to explain by bedded slates and argillites (Vajk, 1951). Because of the decrease in Bouguer values, there appears to be a general thinning of the sediments as one proceeds southwestward from Albermarle to Waxhaw. One should note in this belt, the correlation between the granite at Roxboro, and the long negative deflection of the Bouguer contour lines.

The western boundary of the "slate belt" presents some opportunity for interpretation. Surely there appears to be a major structural break in the area; however, it does not follow what is labeled on the geology map the "Gold Hill fault". Gravity features are displaced to the west. The important feature at Gold Hill appears to be a large northwest trending cross fault. This is shown by the large negative trending from Granite Quarry to Gold Hill. Northward from Salisbury the Gold Hill fault is indistinct, and is not recognizable on the Bouguer gravity map. The "slate belt" area, except for specific granites, appears to be a positive mass which separates two large negative areas: the eastern Coastal Plain, and the western part of the State. An analysis of the western boundary of the "slate belt" is being prepared by Ralph Guidroz and will be presented later.

The western Piedmont is underlain by granite intrusive into mica-gneisses, and other old metasediments. The gradually decreasing Bouguer gravity field, as one proceeds from the "slate belt" westward, is interrupted and modified by intrusives, and possibly by subsurface structures. The first disturbance may be seen in Cabarus County, north of Charlotte. A strong +30 positive appears to be correlated directly with the Concord ring dike. Immediately to the north of this ring dike is a negative associated with the granitic intrusive near Landis. An analysis of this area is being prepared by Benjamin Morgan. Northward from this anomaly is a positive associated with basic rocks near Cleveland. Extending northward to Thomasville, High Point, and into Virginia are a series of Bouguer values which present a steep decreasing gradient towards the west. If granites, or other intrusives disturb this pattern, the only way to recognize it would be to remove the large regional gradient (Vajk, 1951, p. 129-143). It is noteworthy that the large intrusive shown on the State geology map near Charlotte does not present a significant negative value.

A negative near Gastonia may be correlated with granites. Further, granites near Shelby which extend toward Lincolnton are likely the cause of negative trends found over them. A positive trend extends through the south part of Catawba County; this may be related to more basic rocks found in that area. An interesting trend may be observed in Stokes County, where the contour lines broaden around Yadkinville and then turn sharply northwest around Hanging Rock. This sharp change in direction appears to be related to substructure only. Rocks in the area continue to extend northeast-southwest; the gravity picture turns to the northwest. Apparently this results from a deep-seated structure, which has no apparent surface expression.

In Rutherford County, and in Polk County, minor disturbances caused by granites intruded into more basic rocks are likely the cause of the variation in the north trending contour lines.

A sharp deflection in the trend of the contour lines from northeast to east occurs just north of a line from Hickory to Morganton. There is no known rock exposure to which this change in strike may be attributed. Hence the gravity disturbance must be interpreted as a deep-seated feature.

Thus in the Piedmont many gravity features may be related to known rock exposures, however, the large regional gradient, as well as certain trends shown in Stokes County and elsewhere, are caused by deep-seated features, and cannot be explained by surface exposures.

THE MOUNTAINS

Bouguer values in the mountains are characterized by very large negatives. A very strong negative area centered around a -100 milligal contour line in Wilkes County dominates the northeastern part of the mountains. Toward the southwest this negative separates into two arms. One extends along the Tennessee-North Carolina line, and the other trough trends southwestward into Transylvania County. Although still consisting of negative values, a ridge of relatively more positive values separates these negative arms.

The large northern negative is divided by the large (relatively) positive ridge near Spruce Pine just west of the Blowing Rock fault. This steep gradient between the nose and the trough to the northeast, could well be the result of a major structural or lithological break. To the northeast of Spruce Pine occurs a relative gravity high, some 20 to 30 milligals higher than the northeast trending trough. This high coincides with the hornblende gneisses mapped in Ashe and Allegheny Counties. The Blowing Rock window is not outlined on the Bouguer gravity map, but the Mt. Airy granite is by a -95 milligal closed contour. Unfortunately other closed contours cannot be related to known rock types.

The lows to the southwest of Spruce Pine are not as great in magnitude, and tend to be open. They reach a minimum of -90 in Transylvania County, where a contour line closes across the Brevard schist area as shown on the State geologic map. Further, the trend of this anomaly and associated contour lines is at an angle to the strike of the Brevard break. Such suggests that if a discontinuity exists there, the density differential across the boundary is not significant enough to overcome the deep structures giving rise to the -90 milligal values. However, if one drew a line from Hendersonville northward following the minimum values, the line would separate in Avery County: one trend would extend northeast through the -100 values in Wilkes County, and the other would extend straight north into the -100 values in Watauga County. This north line would correspond very closely to the western edge of the Blowing Rock window. Recent work in the Hendersonville area suggests that detailed work will modify the contouring, but will not alter the gross picture presented here.

Southwest of Asheville the absolute negative values are more positive than the adjoining areas to the northwest, or to the southwest. This suggests to the author that the mica-gneiss as displayed on the State geology map is more dense than either the metasediments in Transylvania County or those in the Great Smokies. Because of the lack of geologic detail in this area, minor gravity anomalies cannot be identified or interpreted; however, some large gravity features such as the closed -40 milligal contour in Macon County, are probably the result of subsurface geologic changes.

In Graham, Swain, and Cherokee Counties a disturbance of the northeast-northwest trend, apparently caused by intrusive rocks, is marked by a west to northwest gravity trend. The positive ridge extending northeast-southwest in Macon County, emphasizes and continues this divergence.

In the mountainous area a number of well known geologic features are neither defined nor outlined by gravity. The Andrews-Murphy belt of sediments is not delineated by the gravity pattern. The Webster basic ring dike does not interrupt the regional pattern. The Brevard "fault zone" has a gravity pattern at an angle to the trend of the rock type. Granites which are listed on the map as intrusive do not appreciably alter the gravity pattern. Hence, one must conclude that in the mountainous region much of the pattern developed on the Bouguer map is a result of very deep features. If such is not so, earlier interpretations of these rock types must be incorrect (Eckelman and Kulp, 1956). Perhaps both suppositions are true. The present author suggests that many of the rocks mapped as plutonic granites by earlier workers might possibly be only thin metasediments, a fact already demonstrated at Cranberry, North Carolina, by Eckelman and Kulp (1956).

One might suggest two possible solutions to this apparent dilemma: 1) to re-examine many of the rock types, and 2) attempt to study present gravity data in a manner other than by a contour map.

From the data available it appears that a major structural break extends north-south through the neighborhood of Spruce Pine. Other structural features could well be important but they are masked by other factors. Further, the gravity data confirms recent mapping that indicates that many of the rocks originally mapped as plutonic granites are probably shallow metasediments.

SUMMARY AND CONCLUSIONS

A Bouguer gravity map of the State of North Carolina contoured on a 5 milligal interval, is presented. When this map is compared to a geologic map of the State, only part of the gravity anomalies coincide with exposed geologic features. In the Coastal Plain the gravity anomalies are caused by geologic changes not exposed in surface rocks. In the Piedmont many of the anomalies coincide with, and seem to be explained by, rocks which are exposed at the surface. Only a few of the gravity features in the Mountains are found to coincide with known geologic features.

A number of reasons may be suggested for these discrepancies. These fall into two main categories; either the gravity data are not properly presented, or the geologic map is at fault. Undoubtedly, both are important in various parts of the map. Some examples will illustrate this.

In the northeastern part of the Coastal Plain, a better understanding of the geology would enable one to decide whether the large negative represents a sedimentary basin, or is caused by a deep-seated change. Further, a better knowledge of subsurface structure would permit a separation of local features from deepseated features, so as to permit a better interpretation of the east-west gravity trends underlying the northwest trending Cape Fear arch.

In the Piedmont and in the Mountains, density measurements of the different rock types, and a remapping of many of these rock types according to more recent concepts would be helpful in attempting to interpret the regional Bouguer anomalies. Many gravity features in the Mountains are masked by regional trends. Even so, most of the large features, the deep-seated features, and those which disturb a trend, are readily discernible when comparing the Bouguer gravity map with the North Carolina State Geologic map.

Although the additional geologic information found necessary for satisfactory interpretation of the gravity map is not available at this time, an attempt is being made to separate the deep regional features from the surface gravity features in the Piedmont and Mountains. A progress report on this project will be forthcoming.

REFERENCES

Bott, M.A.P., 1956, A geophysical study of the granite problem: Geol. Soc. London, Quart. Jour., v. 112, p. 45-67.

Eckelman, F. D., and J. L. Kulp, 1956, The sedimentary origin and stratigraphic equivalance of the so-called Cranberry and Henderson granites in Western North Carolina: Amer. Jour. Sci., v. 254, p. 288-315.

Evans, P., and W. Crompton, 1946, Geological factors in gravity interpretation illustrated by evidence from India and Burma: Quart. Jour. Geol. Soc. London, v. 102, p. 211-249.

Geologic Map of North Carolina, 1958, North Carolina Department of Conservation and Development, Raleigh, N. C.

Heiskanen, W. A. and F. A. Vening Meinesz, 1958, The earth and its gravity field: McGraw Hill Book Co., Inc.

Mann, V. I. and F. S. Zablocki, 1961, Gravity features of the Deep River-Wadesboro Triassic Basin of North Carolina: Southeastern

Geol., v. 2, p. 191-215.

Romberg, Frederick E., 1958, Key variables of gravity: Geophysics, v. 23, p. 684-700.

Skeels, Dorr C., 1950, Geophysical data on the North Carolina Coastal Plain: Geophysics, v. 15, p. 409-425.

Stuckey, Jasper L., and Stephen G. Conrad, 1958, Explanatory text for Geologic Map of North Carolina: North Carolina Dept. of Conservation and Development, Bull. 71, 51 p.

Woollard, G. P., 1939, The geological significance of gravity investigations in Virginia: Trans. Am. Geophysical Union, v. 20, p. 317-323.

Woollard, G. P., 1943, Geologic correlation of areal gravitational and magnetic studies in New Jersey and vicinity: Geol. Soc. Am. Bulletin, v. 54, p. 791-818.

Woollard, G. P., and George F. Hanson, 1954, Geophysical methods applied to Wisconsin: Wisconsin Geol. Sur. Bull. 78, Madison, Wisconsin. Gravity Methods, p. 218-222; Gravity Reduction, p. 221.

Woollard, G. P., 1955, Report of the special committee on the geophysical and geological studies of the continents, 1952-1954: Trans. Am. Geophysical Union, v. 36, p. 695-708.

Woollard, G. P., 1959, Crystal structure from gravity and seismic measurements: Journal of Geophysical Research, v. 64, p. 1521-1544.

Vajk, R., 1951, Regional correction of gravity data: Geofisica pura e applicata: v. 19, faec. 3-4, p. 129-143.

Zablocki, Frank S., 1959, A gravity study of the deep river-Wadesboro Triassic Basin of North Carolina: unpublished M. S. Thesis, University of North Carolina, Chapel Hill, N. C., 44 p.

AIRBORNE RADIOACTIVITY SURVEYS - - A GEOLOGIC EXPLORATION TOOL *

by

Robert G. Bates
U. S. Geological Survey
Washington, D. C.

ABSTRACT

Airborne radioactivity surveys provide geologic information on large areas in a short period of time. Preliminary study of the aero-radioactivity data outlines areas of differing geology and indicates the relative complexity of each, thus distinguishing areas of initial interest for subsequent ground surveys. Rapid compilation of a provisional geologic map is possible using aeroradioactivity data to provide continuity between widely-spaced ground traverses. Aeroradioactivity surveys of glaciated regions and those containing extensive alluvial deposits provide little bedrock information. Best results are obtained in areas of varied lithologies, tilted strata, and extensive outcrops or residual soil.

* * *

Airborne radioactivity surveys provide considerable geologic information on large, often relatively inaccessible, areas in a short period of time. Areas of differing geology can be outlined and an idea of the relative complexity of each can be obtained. This tends to pinpoint critical areas of interest for subsequent ground surveys. Aero-radioactivity data can provide geologic continuity between widely spaced ground traverses and thus allow rapid compilation of a provisional geologic map as a guide to additional work.

The best results from aeroradioactivity surveys are obtained in

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* Publication authorized by the Director, U. S. Geological Survey.

areas of tilted strata, moderate relief, and extensive outcrops or residual soil. Glaciated regions and those containing extensive swamps and alluvial deposits provide little bedrock information and should be avoided. The limiting factor on topographic relief is the ability of the aircraft to maintain an altitude of approximately 500 feet above the ground, the normal surveying altitude, and stay within safe operating limits. Initial costs, although seemingly high, are reasonable when the large area covered and the short time required for the survey are considered.

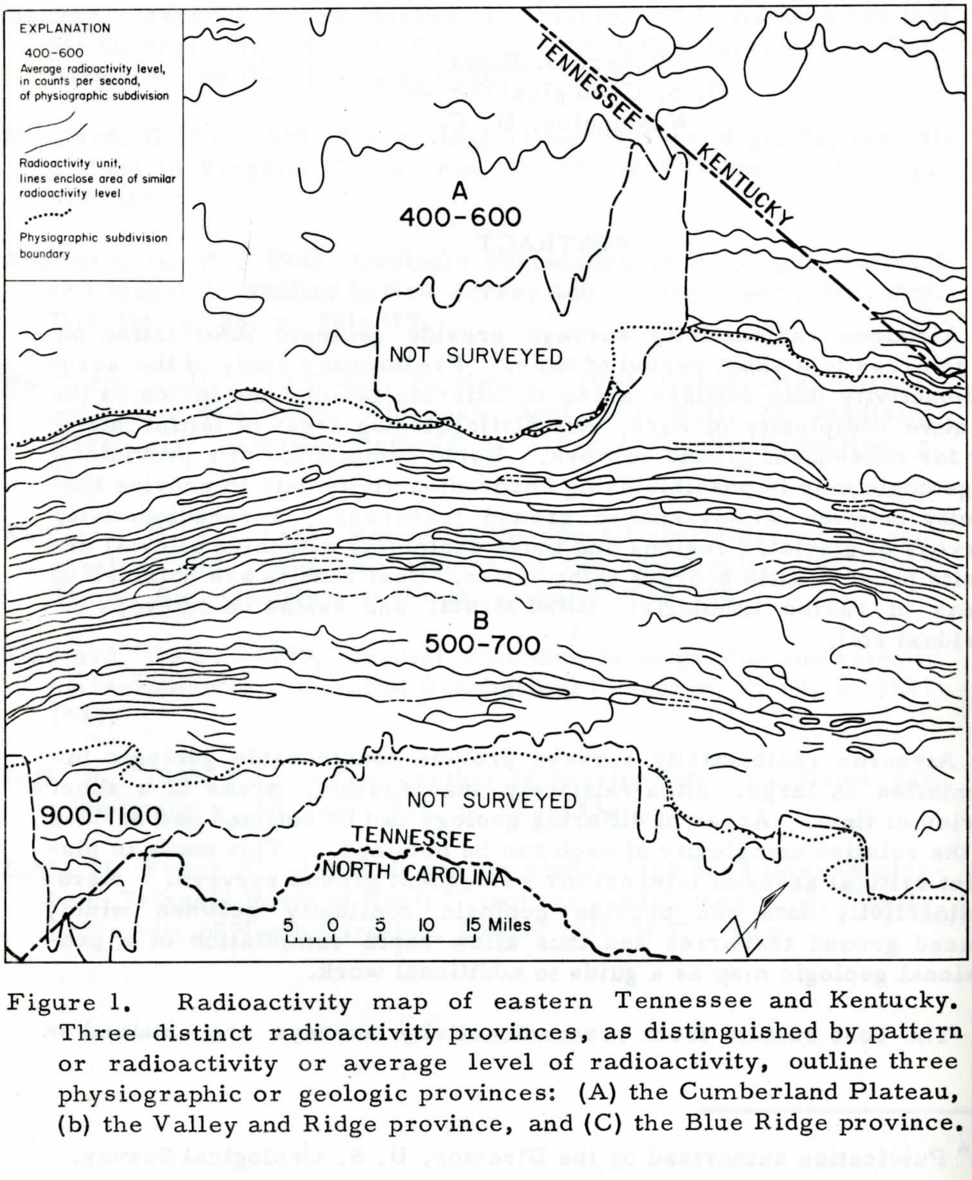


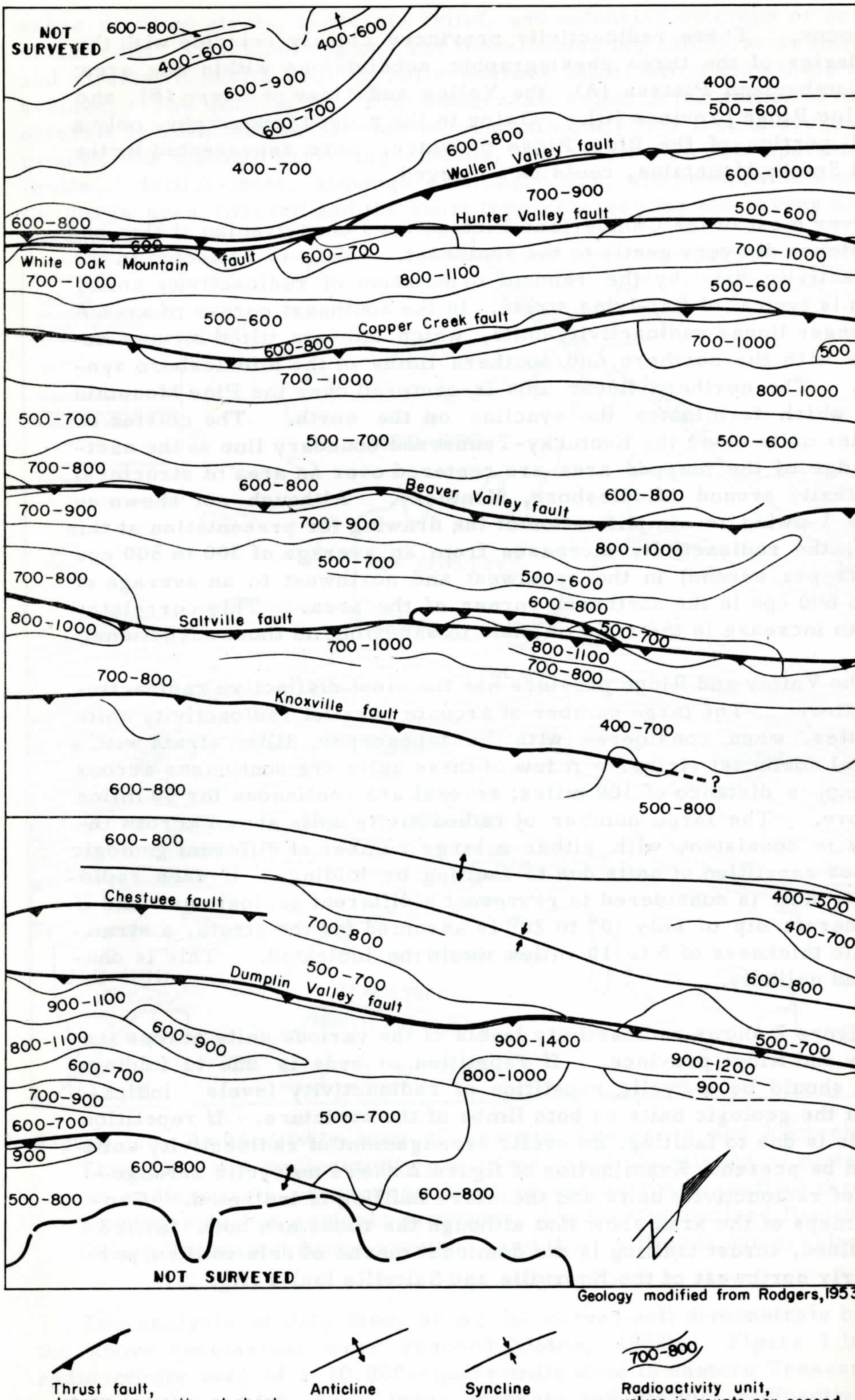
Figure 1. Radioactivity map of eastern Tennessee and Kentucky. Three distinct radioactivity provinces, as distinguished by pattern or radioactivity or average level of radioactivity, outline three physiographic or geologic provinces: (A) the Cumberland Plateau, (b) the Valley and Ridge province, and (C) the Blue Ridge province.

The analysis of data from an actual survey will demonstrate how the above conclusions were reached (Bates, 1962). Figure 1 is a radioactivity map of a 10,000-square-mile area in eastern Tennessee and Kentucky, which shows three separate and distinct radioactivity provinces. These radioactivity provinces closely coincide with the boundaries of the three physiographic subdivisions within the area: the Cumberland Plateau (A), the Valley and Ridge province (B), and the Blue Ridge province (C). Owing to the rugged topography, only a small portion of the Blue Ridge province, here represented by the Great Smoky Mountains, could be surveyed.

Over most of the Cumberland Plateau the Pennsylvanian shales and sandstones dip very gently to the southeast. This is reflected in the radioactivity data by the random orientation of radioactivity units, which is typical of flat-lying strata. In the southeast corner of area A the longer linear radioactivity units, which indicate tilted strata, coincide with the northern and southern limbs of the Middlesboro syncline. The northern linear unit is centered over the Pine Mountain fault which terminates the syncline on the north. The cluster of smaller units along the Kentucky-Tennessee boundary line at the eastern edge of the mapped area are centered over an area of structural complexity around Middlesboro, Kentucky. Although not shown on figure 1 owing to simplification of the drawing for presentation at this scale, the radioactivity increases from an average of 300 to 500 cps (counts per second) in the southwest and northwest to an average of 600 to 800 cps in the northeast corner of the area. This correlates with an increase in the ratio of shale to sandstone in those directions.

The Valley and Ridge province has the most distinctive radioactivity pattern. The large number of arcuate parallel radioactivity units indicates, when considered with the topography, tilted strata with a general northeast strike. A few of these units are continuous across the map, a distance of 100 miles; several are continuous for 50 miles or more. The large number of radioactivity units shown across the valley is consistent with either a large number of different geologic units or repetition of units due to faulting or folding. If each radioactivity unit is considered to represent a different geologic unit and if a moderate dip of only 10° to 20° is assumed for the strata, a stratigraphic thickness of 5 to 10 miles would be indicated. This is considered unlikely.

Figure 2 shows radioactivity levels of the various units across the Valley and Ridge province. If repetition of beds is due to folding, there should be a cyclic repetition of radioactivity levels indicative of the geologic units on both limbs of the structure. If repetition of beds is due to faulting, no cyclic arrangement of radioactivity units should be present. Examination of figure 2 shows no cyclic arrangement of radioactivity units and therefore faulting is indicated. Geologic maps of the area show that although the rocks are both faulted and folded, thrust faulting is the dominant means of deformation, particularly northwest of the Knoxville and Saltville faults (fig. 2).

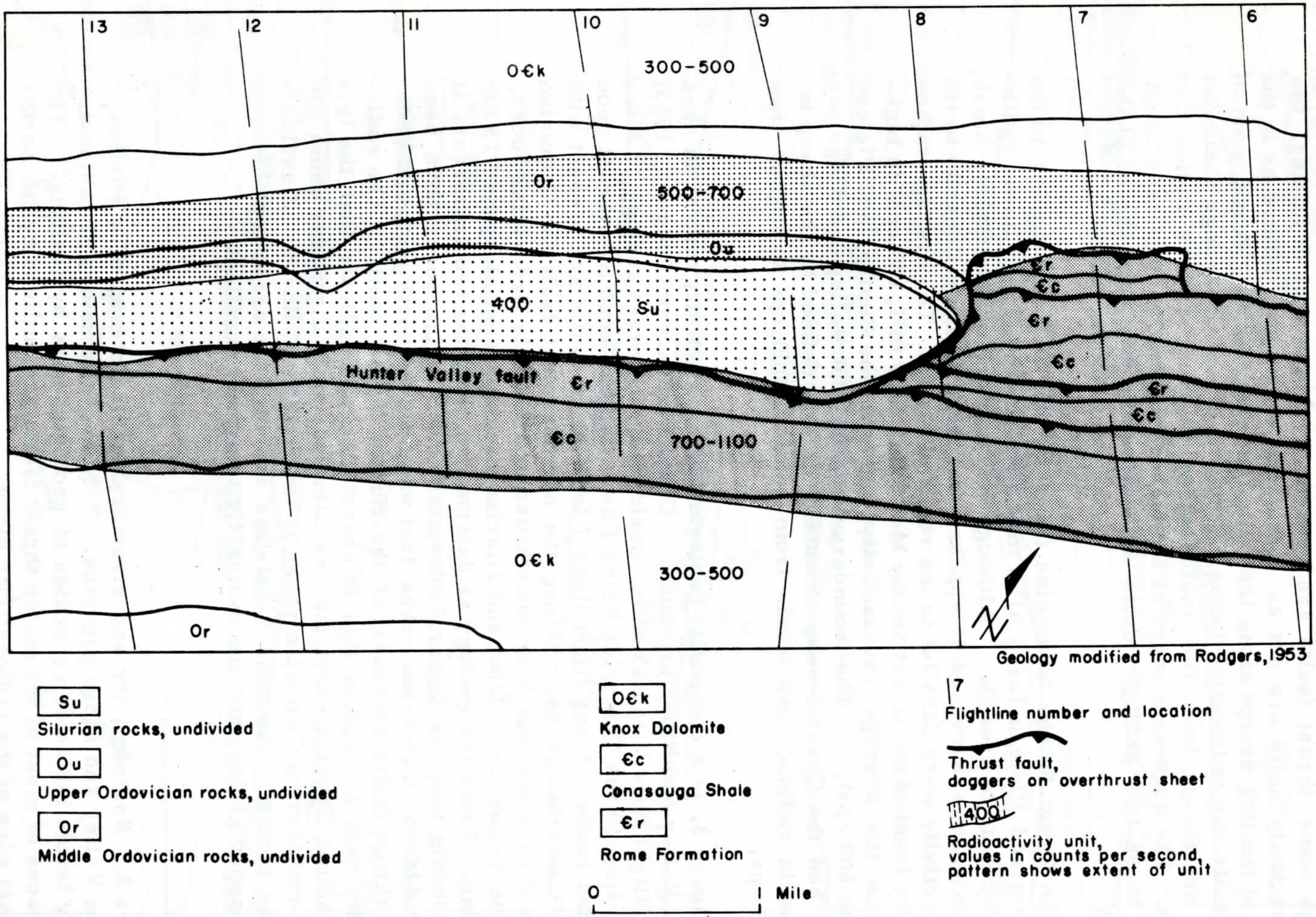

NOT SURVEYED
600-800
400-600
400-600
600-900
600-700
400-700
500-600
600-800
Wallen Valley fault
400-700
600-1000
700-900
600-800
Hunter Valley fault
500-600
600
White Oak Mountain fault
600-700
700-1000
700-1000
800-1100
500-600
500-600
Copper Creek fault
600-800
700-1000
500
700-1000
800-1000
500-700
500-700
500-600
700-800
600-800
Beaver Valley fault
600-800
700-900
700-900
800-1000
500-700
700-800
500-600
600-800
Saltville fault
800-1000
500-700
700-1000
800-1100
700-800
700-800
Knoxville fault
400-700
600-800
500-800
600-800
Chestuee fault
400-500
700-800
400-700
500-700
Dumplin Valley fault
600-800
900-1100
600-900
800-1100
900-1400
500-700
600-700
900-1200
800-1000
900
700-900
500-700
600-700
900
600-800
600-800
500-800
NOT SURVEYED
Geology modified from Rodgers, 1953
700-800
Thrust fault, daggers on overthrust sheet
Anticline
Syncline
Radioactivity unit, values in counts per second
0
5 Miles

Southeast of these faults, deformation is mainly by folding, although some thrust faults are present. In the area of folding, the radioactivity units are not as continuous and as well defined as in the area of faulting except along the Dumplin Valley fault. Along most of the faults the radioactive Rome Formation or the Conasauga Shale has been overthrust from the southeast on to younger, less radioactive rocks. The northwest edges of the high-radioactivity units associated with these two geologic units are therefore accurate traces of the faults.

The Great Smoky Mountains (area C, Fig. 1) are similar to the Cumberland Plateau (area A) in that both lack the strong linear radioactivity units of area B. Although very little of the Greaty Smoky Mountains was surveyed it appears that there is some linearity to the radioactivity units parallel to the regional strike. The average radioactivity level of the Great Smoky Mountains (900 to 1, 100 cps) is higher than the average radioactivity level of the Cumberland Plateau (400 to 600 cps). The boundary between the Valley and Ridge province and the Great Smoky Mountains is well defined by the sharp increase in radioactivity levels from below 1,000 cps to higher than 1,000 cps.

Figure 3, is a composite geologic and radioactivity map of an area in the Valley and Ridge province. Ground traverses (Rodgers, 1953) along flight lines 7 and 13 show considerably different geology. Along flight line 13 the Cambrian Rome Formation has been overthrust upon Silurian rocks. Along flight lines 7 four thrust faults are present within the Cambrian rocks. Along the northernmost fault the Cambrian Rome Formation has been overthrust upon Middle Ordovician rocks, and the Upper Ordovician and Silurian rocks present along line 13 are missing. From the geology as determined along the two traverses, it is probable that the Upper Ordovician and Silurian rocks have been overridden by Cambrian rocks that were moved northwestward by the three thrust faults northwest of the Hunter Valley fault. The radioactivity data strengthen this interpretation and indicate that the less radioactive Upper Ordovician and Silurian rocks disappear under the more radioactive Cambrian rocks in the vicinity of line 8. Considering the control, one-mile flight-line spacing, the agreement between the mapped geology and the radioactivity data is excellent.

Figure 2. Radioactivity and structural geologic map of a portion of the Valley and Ridge province. Non-cyclic nature of radioactivity levels indicates repetition of geologic units by faulting. The traces of most of the major thrust faults are outlined by the northwest edge of the radioactivity highs.


13
12
11
10
9
8
7
6
O€k
300-500
Or
500-700
Ou
400
Su
€r
€c
Hunter Valley fault
€c
700-1100
O€k
300-500
Or
Geology modified from Rodgers, 1953
Su
Silurian rocks, undivided
Ou
Upper Ordovician rocks, undivided
Or
Middle Ordovician rocks, undivided
O€k
Knox Dolomite
€c
Conasauga Shale
€r
Rome Formation
0
1 Mile
7
Flightline number and location
Thrust fault,
daggers on overthrust sheet
400
Radioactivity unit,
values in counts per second,
pattern shows extent of unit

In some areas where geologic units cannot be continuously mapped along strike owing to poor exposures, radioactivity can often be used to trace the units across the covered intervals. Aeroradioactivity surveys are also an excellent geologic reconnaissance tool in areas of igneous and metamorphic rocks. Aeroradioactivity data have been of great help to geologic mapping in the deeply weathered Piedmont of North Carolina (Johnson and Bates, 1960) and in delineating geologic units in the Precambrian rocks of the Driftless area of Wisconsin (Allingham and Bates, 1961).

The thickness of geologic units that can be detected by airborne radioactivity surveys is a function of the time constant of the equipment, the speed of the aircraft, and the contrast between radioactivity of the unit and that of the enclosing rocks. The usual practice of the U. S. Geological Survey is to use a one-second time constant with an airspeed of 150 miles per hour at an altitude of 500 feet above the ground. With this combination of factors, units as narrow as 500 feet are usually detectable.

The radioactivity detection equipment used by the Geological Survey has been described in detail by Davis and Reinhard (1957). It consists of six 4-inch thallium-activated sodium iodide crystals connected in parallel. The signal from the crystals is amplified and sent to 2 vacuum-tube voltmeters. The signal from a radar altimeter is fed into one of the voltmeters in such a fashion as to compensate the signal from the crystals for variations in the altitude of the aircraft. The importance of the elimination of spurious signals due to variations in the aircraft-to-ground distance is illustrated in figure 4. The sharp peak in the center of the uncompensated radioactivity profile (A) is caused by the aircraft being below the surveying altitude of 500 feet (C) as it crossed a sharp topographic high (D). The correct radioactivity level of the formation exposed on the topographic high, 300 cps, is given by the compensated radioactivity data (B). The generally higher level of the uncompensated data (A) is due to the fact that it contains cosmic background of approximately 300 cps which has been removed from the compensated data (B).

Figure 4 also illustrates how radioactivity units of figures 1, 2, and 3 were selected. Experience has shown that the mid-point of the slope between different radioactivity levels usually represents the best

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Figure 3. Composite geologic and radioactivity map shows how radioactivity data, in conjunction with geology mapped along widely separated ground traverses, such as along flight lines 7 and 13, can be used to compile a provisional geologic map.

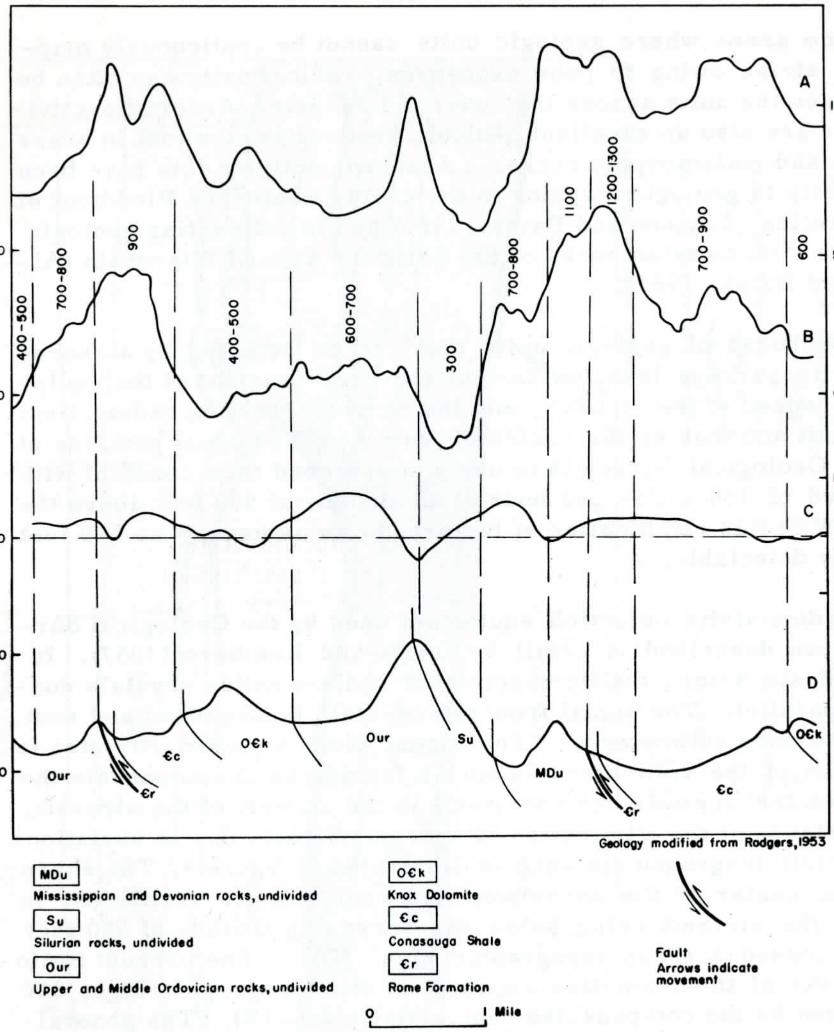


Figure 4. The amount of spurious signal introduced into non-altitude compensated data by variations in the altitude of the aircraft (C) can be obtained by comparison of the uncompensated data (A) with the compensated data (B). The definition of geologic units, using the mid-point method, is shown by comparing profiles B and D.

definition of the boundaries of geologic units. Good definition of boundaries of one or two geologic units within an area might be obtained by contouring the radioactivity data if the contour interval is properly selected. However, this has the disadvantage of leaving other geologic units within the area poorly defined. Also, any diurnal changes in cosmic background or inconsistencies in day-to-day calibration would change the datum, thereby causing shift of the contours away from the geologic boundaries. In the mid-point method, these changes do not affect definition of units because only relative differences, rather than absolute values, are used.

In this nuclear age, recurrent fallout must be considered in radioactivity interpretation. Most areas of the world are sufficiently remote from nuclear testing sites that the distribution of fallout in an area of 10,000 square miles can be considered to be uniform and need not be considered as far as definition of geologic units is concerned. Fallout might become a problem when supplemental lines are flown or the original area is extended after the area has been hit by fallout. However, if the mid-point method, which relies on relative rather than absolute values, is used, geologic definition by the pre-fallout and post-fallout data should be directly comparable.

Airborne radioactivity surveys are a valuable geologic exploration tool. Careful selection of areas, attention to detail during surveying operations, and interpretation by experienced personnel should yield optimum results. When combined with other forms of geophysical information, subsurface as well as surface configuration of geologic units may be obtained, leading to a better understanding of the geologic history of an area.

ACKNOWLEDGEMENT

The airborne radioactivity survey of eastern Tennessee and Kentucky was made by the U. S. Geological Survey in behalf of the Division of Biology and Medicine, U. S. Atomic Energy Commission and is published with the permission of the Commission.

REFERENCES CITED

Allingham, J. W., and Bates, R. G., 1961, Use of geophysical data to interpret geology in Precambrian rocks of central Wisconsin, in Short Papers in the geologic and hydrologic sciences: U. S. Geol. Survey Prof. Paper 424-D, art. 394, p. D-292 - D-296.

Bates, R. G., 1962, Natural aeroradioactivity of the Oak Ridge National Laboratory area, Tennessee and Kentucky: U. S. Geol. Survey Geophys. Inv. Map GP-308.

Davis, F. J., and Reinhardt, P. W., 1957, Instrumentation in aircraft for radiation measurements: Nuclear Sci. and Eng., v. 2, no. 6, p. 713-727.

Johnson, R. W., Jr., and Bates, R. G., 1960, Aeromagnetic and aeroradioactivity survey of the Concord quadrangle, in Short Papers in the geological sciences: U. S. Geol. Survey Prof. Paper 400-B, art. 85, p. B-192 - B-195.

Rodgers, John, 1953, Geologic map of east Tennessee with explanatory text: Tennessee Div. Geology Bull. 58, pt. 2, 168 p.

GEOLOGY OF THE ELK KNOB COPPER DEPOSIT AND VICINITY

WATAUGA COUNTY, NORTH CAROLINA

by

Henry S. Brown

Department of Mineral Industries
North Carolina State College

ABSTRACT

The area containing the Elk Knob deposit is underlain by two major rock types - amphibolite and mica gneiss with schist. Amphibolite is the most abundant rock. Lack of cross-cutting relationships, intricate interlayering of the two rock types, and certain mineralogical features suggest that these rocks are metasediments. All rocks in the area have been deformed into a series of large recumbent folds on the flanks of which are smaller cross folds. Some shear faulting is seen at the Elk Knob deposit.

The Elk Knob deposit is composed of low-grade sulfide mineralization. The predominant sulfide is pyrrhotite but pyrite is common. Copper occurs as chalcopyrite. A small amount of sphalerite is present. Mineralization occurs in three zones, the attitudes of which may be controlled by shear faulting along or near the crest of a recumbent anticline. The mineralized zones are contained in altered amphibolite which is characterized by mineralogical and textural features not common to normal amphibolite in the area. The wallrock alteration is considered to be genetically related to sulfide mineralization.

A limited amount of core drilling has found only low-grade mineralization. Suggestions for possible future prospecting and drilling are given.

INTRODUCTION

Location

The Elk Knob copper deposit is located 8 miles north of Boone, the county seat of Watauga County, North Carolina. The setting of the Elk Knob deposit is in mountainous country of the Blue Ridge Province between the crest of the Blue Ridge to the southeast and the Valley and Ridge Province to the northwest (Figure 1). Approximately 9 square miles of terrain in which the deposit is located has been geologically mapped and is included as part of this investigation. The deposit itself is on the north slope of Elk Knob whose prominent peak is somewhat over a mile above sea level. The old workings of the Elk Knob mine are found at an elevation of 4,200 feet. Maximum relief in the area is 2,200 feet.

History and Production

Following the discovery of copper ore bodies at Ducktown, Tennessee about 1850, there was a period of general prospecting for similar deposits over the entire southeast. From that time until about 1910 nearly one hundred deposits of various sizes were investigated (Kendall, 1953). Owing to its inaccessable location and rather small size, the Elk Knob deposit has not been developed to any significant extent. The veins have been explored by means of two short adits and two probably shallow shafts. Numerous waste dumps containing some sulfides are near these openings. An exploratory cross cut 143 feet in length intersected low-grade mineralization beneath the creek in the No. 1 mineralized zone (Figure 5).

The exact date of mining operations is not known by the author. George B. Hanna observed a "short adit" during his visit to the property in 1874 but he failed to indicate whether or not mining was being carried out at that time (Kerr and Hanna, 1881, p. 225). During his visit to Elk Knob in the early part of this century, Walter H. Weed (1911) noted that no work had been done on the property for many years. Appalachian Sulfides, Inc., Jefferson, North Carolina ran a geophysical survey on the deposit in 1955. Soon afterwards, Sprague and Henwood, Inc., Scranton, Pennsylvania core drilled the deposit for Appalachian Sulfides. No work has been done since that time.

Previous Publications

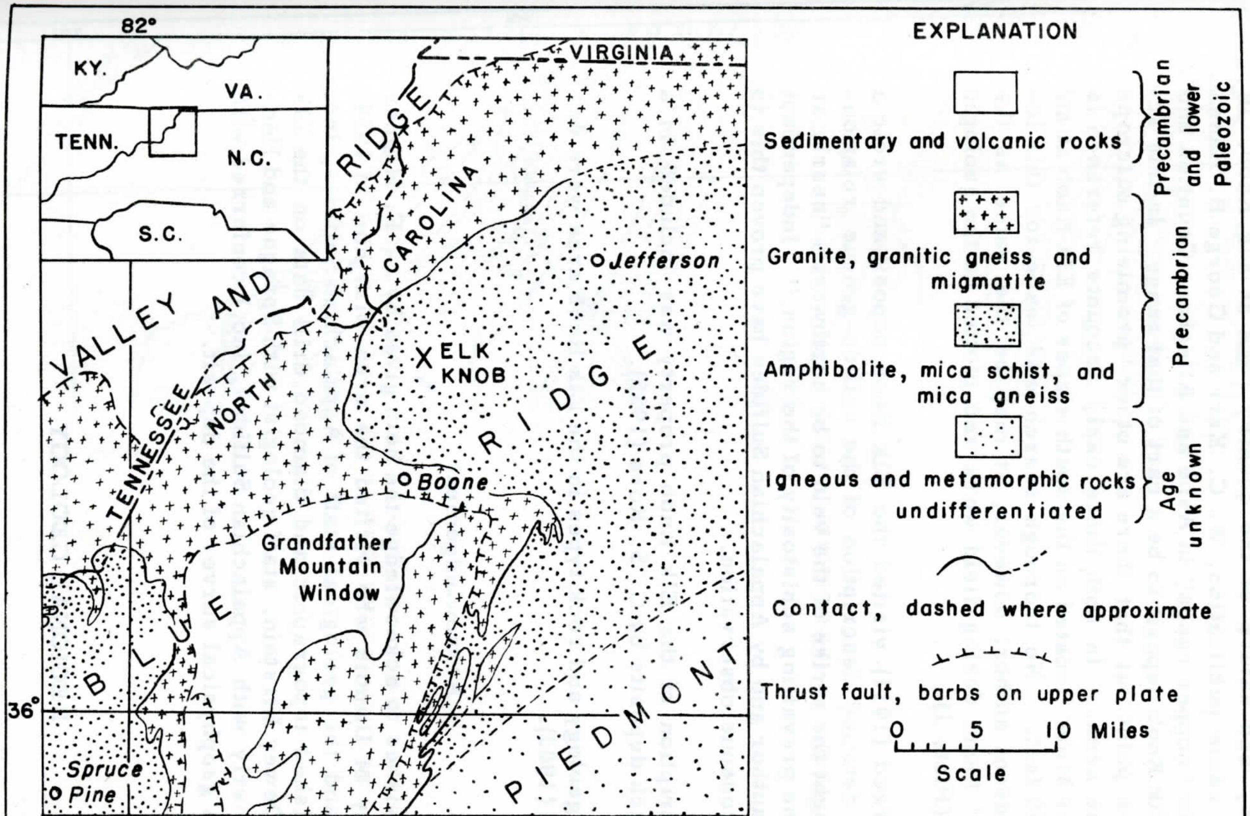


FIG. 1- INDEX MAP SHOWING LOCATION AND GEOLOGIC SETTING OF THE ELK KNOB COPPER DEPOSIT
(Geology after P. B. King (1954) and Bryant & Reed (1960))

In Volume I of the Report of the Geological Survey of North Carolina the State Geologist, W. C. Kerr (1875) lists the sulfide minerals, width of the vein, and nature of the country rock at Elk Knob. In Volume 2 of the same publication, W. C. Kerr and George B. Hanna (1881) refer to the "copper range" in Ashe and Alleghany Counties and considered the Elk Knob deposit to be a part of that range. In this account the authors point out that there are other "promising outcrops of gossan" in the area. In both these early accounts reference is made to a "Miller Mine" located on the south slopes of Elk Knob at an elevation of 4,000 feet. No thorough search was made for this locality by the present author; however, it may be the same as the "prospect pit(?)" found during field work and plotted on the geologic map of the area (Plate 1).

Walter H. Weed (1911) visited the Elk Knob deposit and wrote a somewhat more detailed description of the sulfide-gangue relationships. He thought the strike of the vein to be northwest - "nearly at right angles to the prevailing schistosity of the region." Independent surveys by the author and by Appalachian Sulfides have proven this to have been an erroneous observation.

A brief description of the Elk Knob property was included in a study of many such deposits by C. S. Ross (1935).

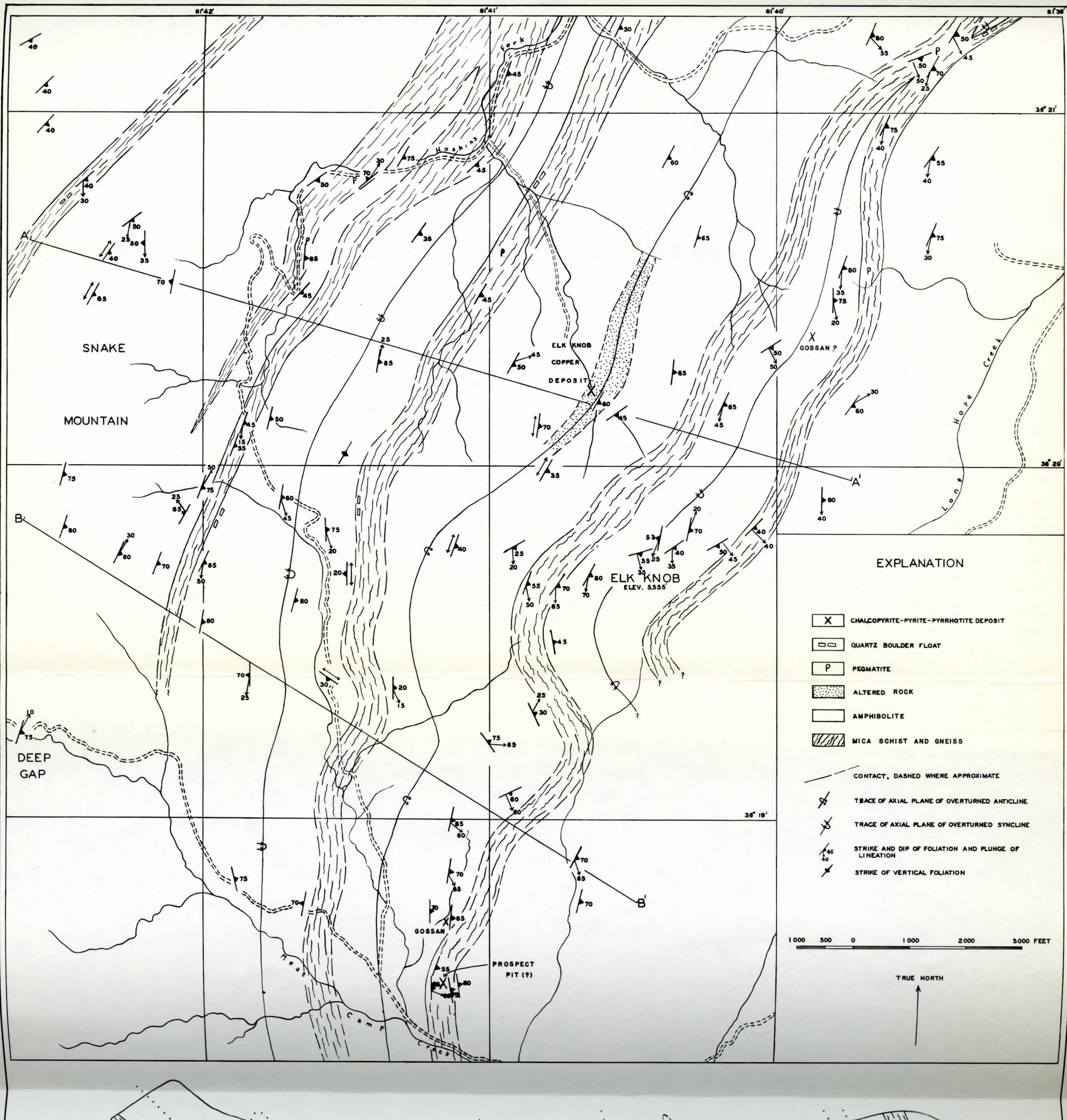
The general geology and rock types in the Elk Knob area were described by Keith (1903).

Acknowledgement

The writer wishes to acknowledge the help given by A. F. Hagner of the University of Illinois who visited the area with him in 1954. Philip Eckman and the geological staff of Appalachian Sulfides, Inc. generously furnished topographic and diamond drill data on the Elk Knob deposit. Dewey Kirstein, staff geologist with Sprague and Henwood, Inc. (formerly with Appalachian Sulfides, Inc.) conferred with the author on the geophysical survey of the deposit.

REGIONAL GEOLOGY

Rocks



GEOLOGIC MAP OF THE ELK KNOB-SNAKE MOUNTAIN AREA WATAUGA COUNTY, NORTH CAROLINA

PLATE I

GEOLOGY BY HENRY S. BROWN, 1954

All rocks in the vicinity of the Elk Knob deposit have been metamorphosed to the kyanite-almandine-muscovite subfacies of the almandine-amphibolite facies as defined by Turner and Verhoogen (1960). Some zones show various degrees of retrogressive metamorphism to the greenschist facies.

There are two major rock types in the Elk Knob area. The principal rock is an amphibolite. Interlayered conformably with the amphibolite is a series of mica gneisses, which are in part schistose. Locations of these rocks are shown on the general geologic map of the Elk Knob area (Plate 1).

Amphibolite. - The predominant rock in the Elk Knob area is a dark green to black, strongly foliated rock which has hornblende, epidote, and plagioclase as its essential minerals. Quartz is usually present as disseminated grains and stringers and as joint and small fracture fillings. Occasionally zones within this rock are found to contain considerable amounts of euhedral almandite. Crystals up to an inch in diameter may be found. Subhedral almandite often occupies eyed structures with quartz filling the pressure shadows. Outcrops are usually found along stream beds and on ridge tops. Continuous tracing of a single rock unit is impossible due to talus on steep slopes and general soil cover over most of the area.

Hornblende is the most abundant mineral and in some layers makes up more than 90 percent of the rock. The crystals, ranging from one to ten mm in length, lie in the plane of foliation and are generally parallel imparting a lineation to the rock. In thin section, hornblende is light to dark-green with pleochroism ranging from pale yellow-green (X direction) to smoky blue-green (Z direction). The index of refraction (N_Z) ranges from 1.655 to 1.680 with the more pale varieties having the lowest index. The average index of hornblende is 1.668. The relatively low index of refraction and other properties suggest that Mg/Mg+Fe in the hornblende is greater than 50 percent (Parker, 1961). Locally, most often in zones characterized by shearing, hornblende crystals have been partially altered to chlorite and biotite. These zones also contain a little calcite which may have resulted from the breakdown of hornblende. This type of alteration is most pronounced at the Elk Knob copper deposit.

Epidote occurs as pale yellow-green grains interspersed with hornblende crystals and as richer streaks and zones within the amphibolite. At the Elk Knob mine, layers of rock three to four feet thick have epidote as the most important constituent. Massive epidote is also found filling joints and fissures.

The amount of plagioclase in the amphibolite is small, not more than 10 percent, but it is generally present. Measurement of extinction angles in the zone normal to (010), and determination of index of refraction, have established that the mineral ranges in composition from albite to andesine, with the vast majority occurring as oligoclase. Plagioclase occurs in larger amounts in certain parts of the Elk Knob copper deposit; here it is somewhat more sodic than the normal plagioclase.

Quartz, like epidote, by its occurrence in streaks and veinlets adds pattern to the otherwise monotonous dark-green color of the amphibolite. It may fill crests and toughs of small drag folds or it is elongated in "pencils" parallel to the lineation produced by hornblende crystals. Occasionally discordant "clots" of milky quartz are found in coarser-grained, contorted portions of amphibolite. As exposed in outcrops, these "clots" range in size up to a foot across and two or three feet long. The resemblance of the quartz masses in amphibolite to small granitic pegmatites in the mica gneisses and schists of the area is striking.

Minor mineral constituents of the amphibolite include rutile, sphene, apatite, zircon, sericite, magnetite and pyrite.

<u>Mica gneiss</u>. - This rock occurs as concordant layers within the amphibolite. The layers range in width from a few inches to several hundred feet. Fresh surfaces are light gray but outcrops weather dark gray to brown. The rock is medium - to coarse-grained and has strongly developed foliate structure. Muscovite, biotite, oligoclase and quartz are the essential minerals, with the percentages of individual essential minerals varying such that the rock ranges in composition from a mica schist, to a mica gneiss, to small amounts of micaceous quartzite. Almandite, kyanite, and untwinned microcline are important accessory minerals. Kyanite is not always present, but may make up 10 or more percent of some layers. At the north end of Snake Mountain and near the north base of Elk Knob lenses and layers of milky quartz up to 4 feet in width are found associated with, and parallel to, layers of mica schist and gneiss.

Granitic pegmatites are found in the mica gneiss and schist layers. Most of the pegmatites are small - on the order of a foot or so in diameter. One was completely removed from the enclosing rock and found to contain large anhedral crystals of muscovite, quartz, a little microcline and small, euhedral crystals of black tourmaline. Although these pegmatites are small, some have been exploited by local persons for their mica content.

Origin of the Rocks

Keith believed the mica gneiss was metamorphosed from an ancient, extensive granite and the amphibolite, due to richness in hornblende, represented former gabbroic intrusions into the granite. He called the mica gneiss the Carolina Gneiss, and named the amphibolite Roan Gneiss. Since most geologists no longer subscribe to these views on origin, the names Carolina Gneiss and Roan Gneiss have been abandoned in favor of more descriptive terms.

The mica gneisses are continuous along the strike, with and similar lithologically to, the Wissahickon Schists of Virginia which are thought to have been derived from ancient sedimentary rocks. Jonas (1932) states that in central Virginia the schistosity is parallel to the original bedding. Intricate interlayering of the mica gneisses and schists with amphibolite lead Kulp and Poldervaart (1956) to the conclusion that in the Spruce Pine district these formations are metamorphosed sediments.

In the Elk Knob area mica gneiss contains numerous porphyroblasts of kyanite in certain of its more micaceous layers indicating that the original rock contained abundant aluminum. In other layers the rock is composed almost entirely of quartz grains and therefore constitutes a quartzite. These mineral compositions are most easily explained by assuming the mica gneiss to represent metamorphic equivalents of arenaceous and argillaceous sediments.

The average index of refraction of hornblende in amphibolite suggests that the Mg to Mg +Fe ratio is well over 50 percent. This means that the amphibolite is the metamorphosed equivalent of a calcium-magnesium rich rock - possibly an impure dolomite.

Contacts of mica gneiss and schist with amphibolite are characterized by much intimate interlaying. No cross cutting relations between the two rock types are observed.

It is believed that the amphibolite and interlayered mica gneisses are the metamorphoses equivalents of a thick sequence of sedimentary rocks composed of impure dolomite with smaller amounts of shale and minor sandy layers. During metamorphism the impure dolomite became amphibolite and the argillaceous and arenaceous layers became mica gneiss. The interlayering of these rocks and mineralogical variations within rock units probably represent normal facies change conditions encountered in all sediments.

Since pegmatites at Elk Knob are small and confined to mica schist and gneiss layers whose mineralogy they essentially duplicate, it is probably that they are metasomatic in origin.

Structure

Rocks in the Elk Knob area have been extensively deformed. The intensity of deformation is perhaps not so great as in the Piedmont to the southeast, but distinctly greater than in the Valley and Ridge province to the northwest. The regional trend of schistosity and foliation is northeast. In general, the dip is to the southeast.

Folding. - Forces which originally deformed and metamorphosed the rocks at Elk Knob came from the southeast and folded them into a series of anticlines and synclines which actually might be more properly classified as huge drag folds (Plate 1). The folds are overturned to the northwest. The presence of these larger folds is suggested by evidence from fracture cleavage in quartz veinlets, attitude of foliation and lineation, small scale drag folding, and the outcrop pattern of amphibolite and mica gneiss and schist. Smaller drag folds in most outcrops are outlined by streaks and zones of pale green epidote crystals and white stringers of quartz, and point to the positions of larger structures. These folds plunge to the southwest in most of the area shown on Plate 1.

Minor folding may have occurred since the major period of deformation. Smaller folds are on the flanks of the large folds and the axes of the two meet at a rather high angle. This suggests that more than one cycle of metamorphism has affected the Elk Knob area. Kulp and Poldervaart (1956) are of the opinion that rocks in the Spruce Pine district were subjected to metamorphism at least twice.

Considered on a large scale, all the area mapped around the Elk Knob deposit may be part of the southeasterly dipping limb of a large synclinorium. Regional outcrop patterns (Figure 1) suggest such a feature exists. The concept is aided by structural features in the Elk Knob area.

The regional geology in North Carolina northeast of Elk Knob is poorly known.

Faulting. - At Elk Knob no significant excavations have resulted from road building and the mine workings are very limited. For these reasons the part played by faulting in shaping the geology is virtually unknown. It is certain that some shear faulting has occurred for it can be seen at the Elk Knob mine and possibly played a role in localizing mineralization. Since the deposit lies on or near an anticlinal axis it appears that some shearing has accompanied folding. Perhaps shear faulting has been a controlling factor in the emplacement of the large quartz veins in the mica gneiss and schist layers. The role of normal faulting at Elk Knob, if it exists, is not known.

Joints. - There are two major joint sets in the Elk Knob area. Perhaps each is related to a metamorphic cycle. One set strikes in a general east-west direction and dips almost vertically. The less important set strikes northwest and dips to the southwest at a rather high angle (Figure 2). These joints are sometimes filled with quartz or epidote.

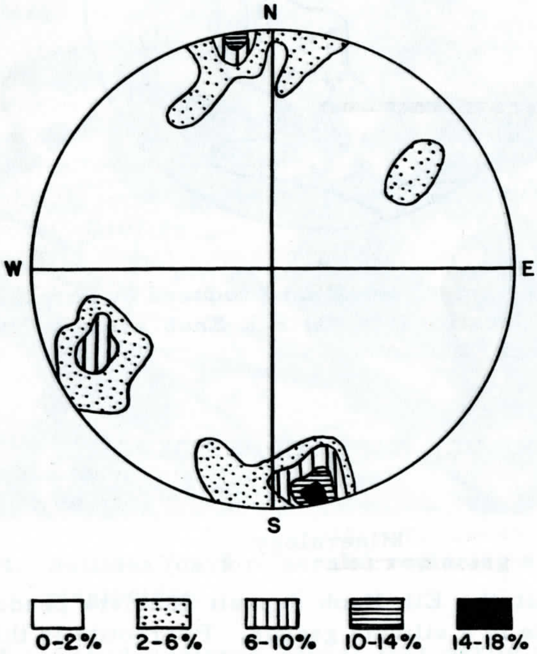


Figure 2. Contour diagram of 51 joints in the Elk Knob area, plotted on upper hemisphere.

Lineation. - The approximate parallelism of hornblende needles imparts a lineation to most outcrops of amphibolite. Figure 3 summarizes the direction and plunge of lination at Elk Knob. The "girdle" of points essentially parallels the strike of foliation. The majority of measurements show lineation plunging southward. Since folds in the amphibolite also seem to plunge generally toward the south and southwest, lineation probably parallels or almost parallels the fold axis. However, not all hornblende needles plunge to the south. It is interesting to note that near the Elk Knob deposit lineation is essentially horizontal and northwest of the deposit lineation plunges to the northeast (Plate 1).

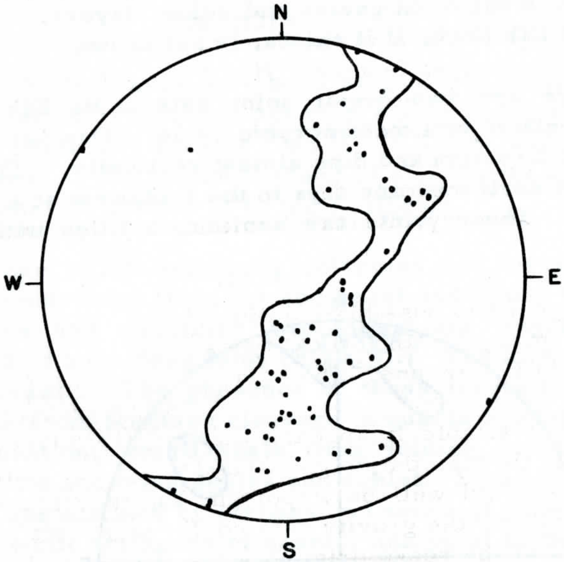


Figure 3. Point diagram of lineation produced by hornblende crystals from 51 localities in the Elk Knob area, plotted on lower hemisphere.

THE ELK KNOB COPPER DEPOSIT

Mineralogy

Mineralization at the Elk Knob deposit consists predominantly of pyrrhotite and pyrite in a silicate gangue. Pyrrhotite is the most abundant sulfide. Copper, occurring as chalcopyrite, makes up a small fraction of one percent of the mineralized zones. Traces of sphalerite are found. In addition to the sulfides, some gold has been reported (Ross, 1935, p. 87). Gangue minerals are hornblende, actinolite, albite, biotite, barite, and small amounts of magnetite, chlorite, sericite, garnet, quartz, calcite, epidote, and untwinned microcline. The degree of mineralization at Elk Knob is best comprehended by referring to the diamond drill log which accompanies this paper as an appendix.

Sulfides occur as disseminated grains and as irregular stringers and bands up to 6 inches thick. Rather pure bands of either pyrrhotite or pyrite are common and occasionally thin stringers of almost pure chalcopyrite are found. Massive pyrrhotite bands may contain corroded pyrite cubes. Disseminated sulfides are usually mixtures of ore minerals with pyrite being the most abundant.

In thin sections sulfides are seen to fill fractures and replace all gangue minerals but seem to have been most successful in replacing albite and actinolite (Figure 4). While fracture and shear zones were undoubtedly important avenues through which sulfide forming fluids moved to the sites of deposition, mineralization was accomplished primarily through replacement rather than fracture filling.

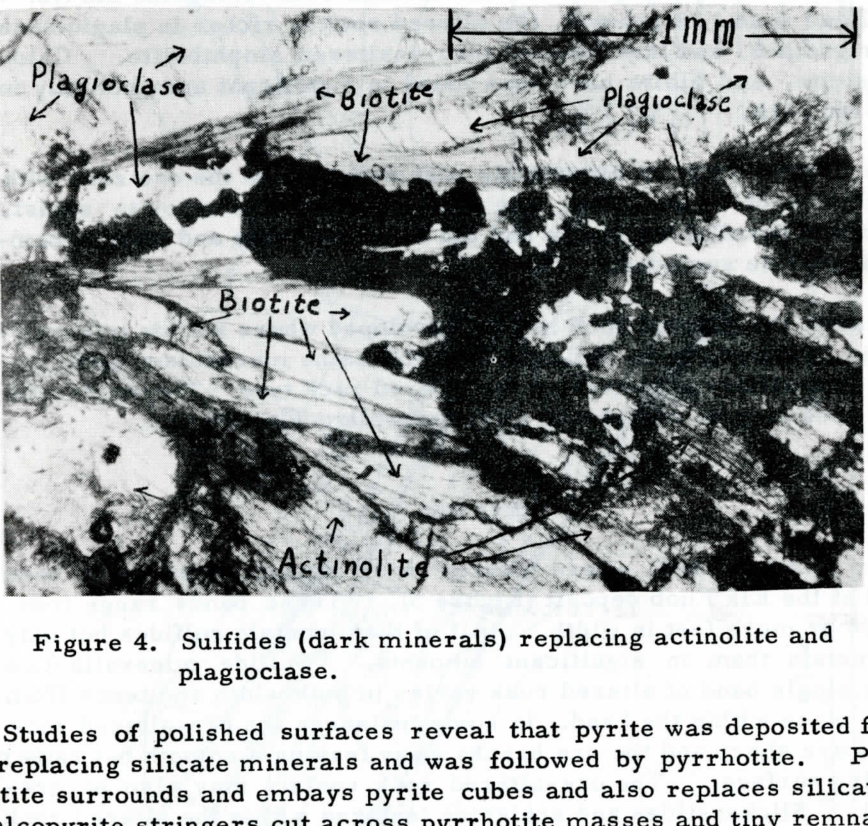


Figure 4. Sulfides (dark minerals) replacing actinolite and plagioclase.

Studies of polished surfaces reveal that pyrite was deposited first by replacing silicate minerals and was followed by pyrrhotite. Pyrrhotite surrounds and embays pyrite cubes and also replaces silicates. Chalcopyrite stringers cut across pyrrhotite masses and tiny remnants of pyrrhotite and pyrite are found enclosed within chalcopyrite. This evidence strongly suggests that chacopyrite followed pyrrhotite in the paragenetic sequence. Sphalerite relationships are not too clear. Most sphalerite seems to be of the same age or later than chalcopyrite, however, some sphalerite grains are completely enclosed in pyrite cubes as if they were deposited along with or before the pyrite.

Wallrock Alteration

Sulfides at Elk Knob are contained in a rock which has been recrystallized and altered from normal amphibolite in the area. Abundant minerals in the altered rock are hornblende, actinolite, albite, biotite, epidote, sericite, chlorite, and untwinned microcline. Actinolite is almost colorless to pale yellow-green in thin section. Small bits of green hobnrlende frequently occur along boundaries of actinolite crystals in such a manner as to suggest corrosion remnants. Small biotite crystals are often enclosed by larger acitinolite crystals. Albite and untwinned microcline show incipient alteration to sericite. Biotite is occasionally altered to chlorite or muscovite. Biotite crystals are sometimes found with bleached edges which contain specks of magnetite. Epidote is abundant in parts of the altered rock alongside the No. 1 mineralized zone. In general, the altered rock is richer in plagioclase, coarser grained, and less foliated than unaltered amphibolite. Chlorite, calcite, and albite have been found in significant amounts only in the altered rock.

The altered rock is essentially structureless in the ore zone with the exception of some rather thin bands of biotite-muscovite schist. These bands parallel the strike and dip of the ore vein and often accompany slickenside surfaces.

Because the altered rock is best developed where sulfide mineralization is greatest, it is believed that the same mechanism which deposited the sulfides also created the altered rock type. Therefore, the altered rock may be considered a type of wallrock alteration.

Structure

Four distinct bands where altered rock predominates have been mapped at the Elk Knob deposit (Figure 5). These bands range from 30 to 100 or more feet in width. All of them contain sulfides but only three contain them in significant amounts. Sulfide mineralization within a single band of altered rock varies in both width and tenor from place to place within the band. In some instances the ore-altered rock contacts are sharp and the ore breaks away leaving a smooth but rather undulating surface. The ore-altered rock contact may also be gradational. Slickenslides and schistose textures within the altered rock zones suggest that shearing may have played a role in localization of mineralization.

The No. 1 mineralized zone at the entrance to the adit is approximately 12 feet wide but narrows to about 2 feet at the deepest penetration of the adit. Limited diamond core drilling by Appalachian Sulfides, Inc. reveals that this vein diminishes in both width and concentration of sulfides along strike in both directions from the adit opening.

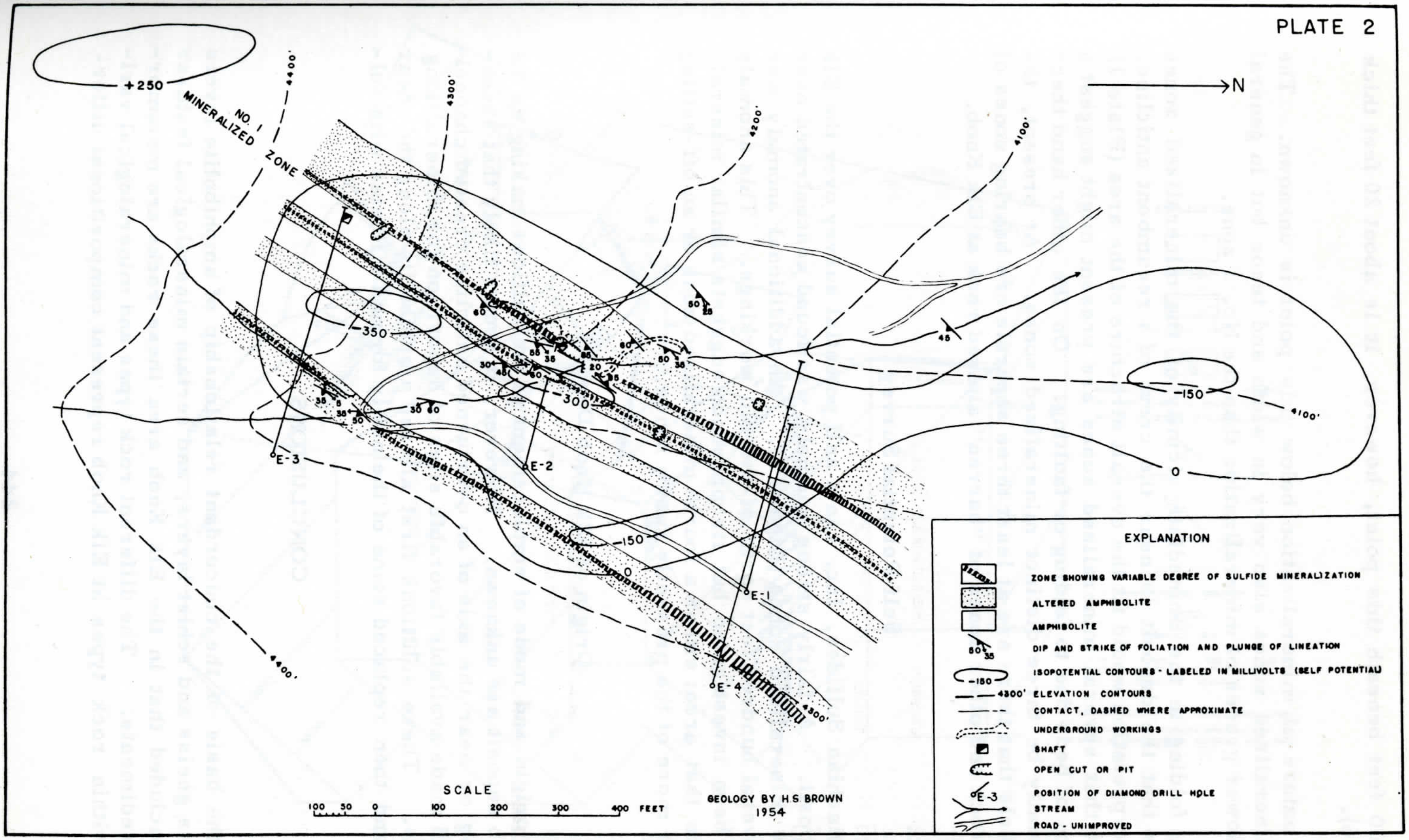


Figure 5. Geologic and topographic map of the Elk Knob copper deposit, North Carolina.

About 200 feet beneath this point, however, it is about 20 feet thick (Figure 6).

The nature of mineralization below this point is unknown. The other mineralized zones also vary in width and tenor but in general contain lower grades of mineralization than the No. 1 zone.

Drag folding in the immediate vicinity of the mineralized zones suggests that the deposit is near the crest of a recumbent anticline. This interpretation would fit the overall structure of the area (Plate 1). The fact that several mineralized zones are present might suggest a repetition of beds due to folding or faulting. On the other hand there may actually be three distinct mineralized zones. At present, the author feels that there are at least three separate ore bearing zones of altered rock and other zones of "barren" altered rock at Elk Knob.

Self Potential Survey

Appalachian Sulfides, Inc. ran a self potential survey over the Elk Knob deposit. A fairly strong anomaly was found concentrated over the three mineralized zones (Figure 5). An additional anomaly was found several hundred feet north of the old workings. This anomaly has not been investigated but its presence suggests similar mineralization in that area; either a fourth mineralized zone or an off-setting of one or more of the presently known zones.

Origin of Elk Knob Deposit

The origin and mode of emplacement of the sulfides making up the Elk Knob deposit are unknown. However, it seems likely that shearing along or near the axis of an overturned anticline created channelways and made available favorable sites of deposition for mineralizing solutions. These solutions first altered amphibolite along the shear zones, and then replaced some of the newly formed silicates with sulfides.

CONCLUSIONS

On the basis of the concordant relationship of amphibolite layers with mica gneiss and schist layers, and certain mineralogical features it is concluded that in the Elk Knob area these rocks are metamorphosed sediments. The different rock types and mineralogical variations within rock types at Elk Knob represent compositional differ-

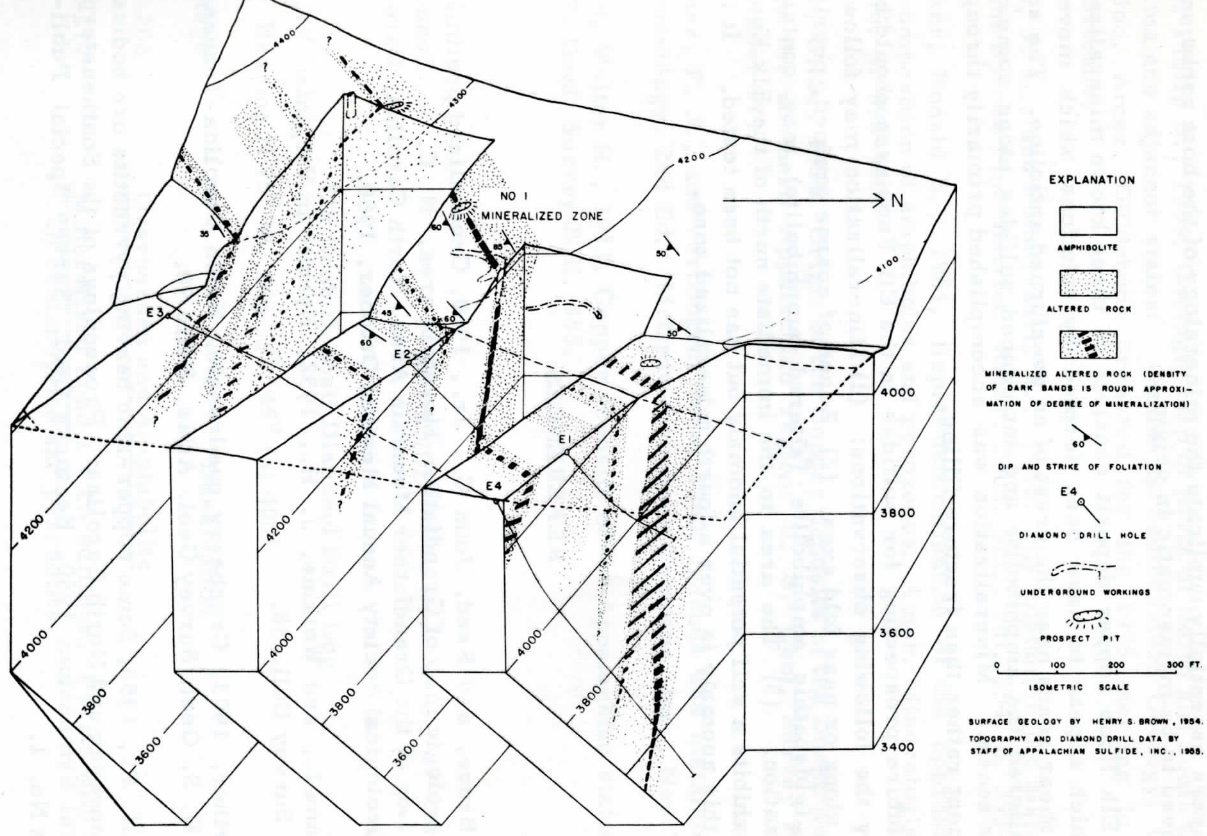


Figure 6. Isometric projection of the Elk Knob deposit.

ences inherited from the sediments.

The rather small "granitic" pegmatites found in mica gneiss and schist layers essentially duplicate the mineralogy of the host rocks and are believed to be metasomatic in origin.

The Elk Knob copper deposit consists of three known mineralized zones which appear to have been formed by solutions which moved through shear zones near the crest of an overturned anticline. The solutions altered the amphibolite and introduced sulfides along some of the shear zones. Mineralization was accomplished primarily through replacement rather than fracture filling.

Any future prospecting for sulfides in the Elk Knob area should be guided by the following observations: (1) Mineralization may follow shearing along or near fold axes. (2) Zones of coarse grained, poorly foliated, feldspathic amphibolite (altered amphibolite) may contain mineralization. (3) The area to the immediate north of the Elk Knob deposit exhibits a self potential anomaly but has not been tested. It is possible this anomaly is over a fourth mineralized zone.

REFERENCES

Bryant, Bruce, and Reed, John C., Jr., 1960, Generalized preliminary geologic map of Grandfather Mountain area, N. C. - Tenn.: Road Log of the Grandfather Mountain Area, North Carolina, Carolina Geological Society Annual Meeting October, 1960.

Jonas, Anna I., and Watkins, J. H., 1932, Kyanite in Virginia: Va. Geol. Survey Bull. 38.

Keith, Arthur, 1903, Cranberry quadrangle, North Carolina-Tennessee: U. S. Geol. Survey Geol. Atlas, Folio 90.

Kendall, H. F., 1953, Some copper-zinc bearing pyrrhotite ore bodies in Tennessee and North Carolina: . Proceedings of the Southeastern Mineral Symposium 1950, Kentucky Geol. Survey Special Publication No. 1.

Kerr, W. C., 1875, Report of the Geological Survey of North Carolina: vol. 1, p. 273.

Kerr, W. C., and Hanna, Geo. B., 1881, Ores of North Carolina: Geology of North Carolina vol. 2, p. 225.

King, Philip B., 1954, Geologic map of parts of North and South Carolina and adjacent states: Guides to Southeastern Geology, Geol. Soc. Amer. Guidebook prepared for the 1955 meeting in New Orleans.

Kulp, J. L., and Poldervaart, A., 1956, The metamorphic history of the Spruce Pine district: Amer. Joun. Sci., vol. 254, p. 393-403.

Parker, Ronald B., 1961, Rapid determination of the approximate composition of amphiboles and pyroxenes: Amer. Mineralogist,vol. 46, p. 892-900.

Ross, C. S., 1935, Origin of the Copper deposits of the Ducktown type in the southern Appalachian region: U. S. Geol. Survey Prof. Paper 179.

Turner, F. J., and Verhoogen, John, 1960, Igneous and metamorphic petrology, 2nd Ed.: McGraw-Hill Book Company, Inc., New York.

Weed, Walter H., 1911, Copper deposits of the Appalachian states, U. S. Geol. Survey Bull. 455.

APPENDIX

Elk Knob Deposit Diamond Drill Log*

E-1 Bearing N 75° W, Dip 55°; 45° (a) 400'

Footage	Description
0-206	Overburden and Amphibolite
206-217	Mineralized Zone 1 - 2% sulfides. Pyrite with traces of chalcopyrite and pyrrhotite.

* Abstracted from the record kept by Appalachian Sulfides, Inc.

(E-1 - contd.)

Footage	Description
217-323	Amphibolite
323-427	Mineralized Zone 1 - 2% sulfides. Pyrite with traces of chalcopyrite and pyrrhotite.
427-451	Amphibolite slightly mineralized, 1 - 2 inch bands of pyrite at 346'.
451-600	Amphibolite
	End of hole

E-2 Bearing N 75° W; Dip 55°

Footage	Description
0-288	Overburden and Amphibolite
288-311	Mineralized Zone (0.6% Cu)

288	-	290	50%	sulfides
290	-	296	3%	sulfides
296	-	297	50%	sulfides, chalcopyrite and pyrite about equal
297	-	298.4		barren
298.4	-	299		pyrrhotite
299	-	304.5	5%	sulfides
304.5	-	305		pyrrhotite
305	-	311		minor mineralization except 1' pyrrhotite-pyrite band

Footage	Description
311-337	Amphibolite
	End of Hole

E-3 Bearing N 75° W; (Dip approx. 50°)

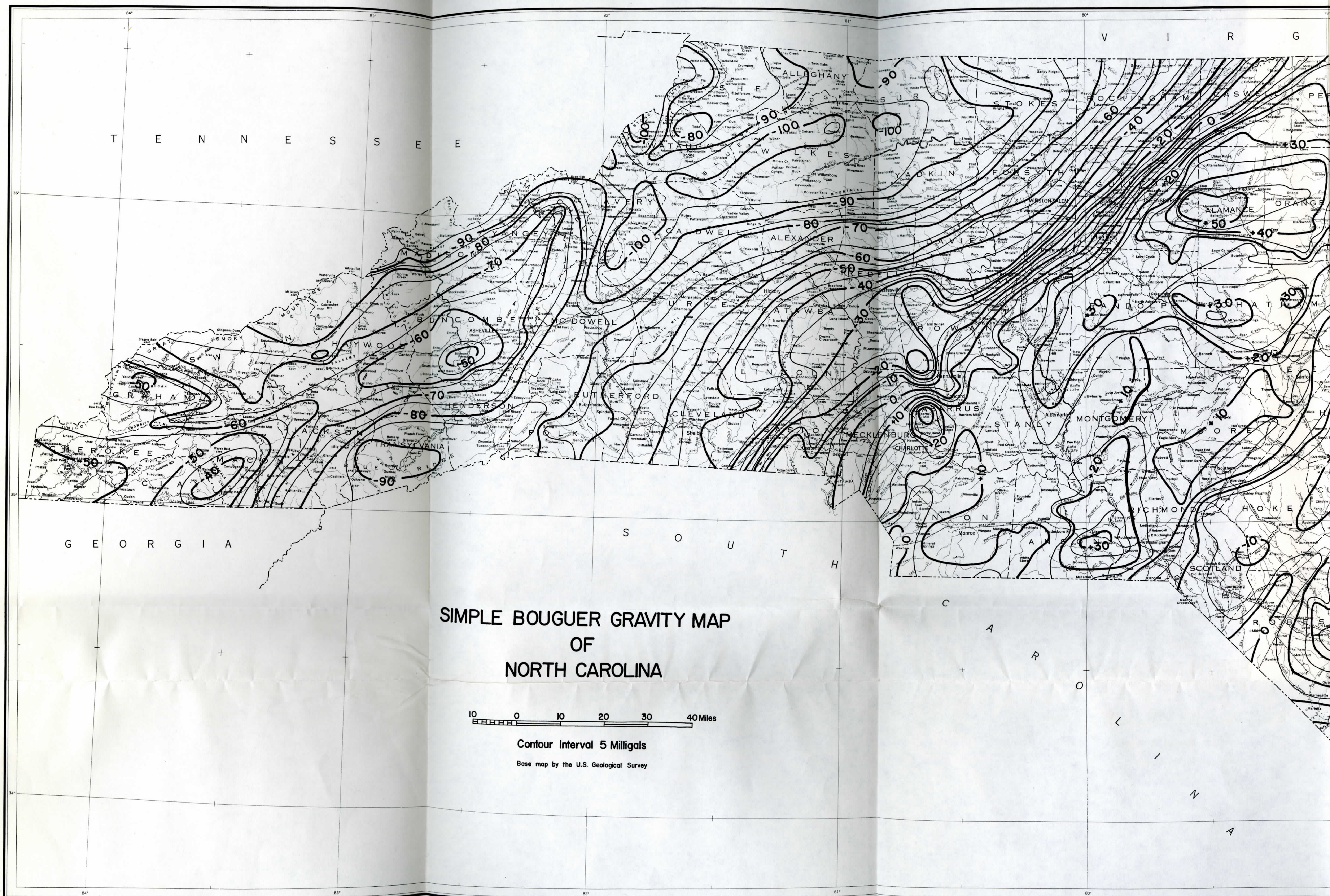
Footage	Description
0-85	Overburden and Amphibolite

(E-3 - contd.)

Footage	Description
85-115	Mineralized Zone 1 - 2% sulfides
115-145	Amphibolite
145-153	Mineralized Zone - 1 - 2% sulfides.
153-260	Amphibolite
260-280	Mineralized Zone 1 - 2% sulfides
280-344	Amphibolite
344-350	Mineralized Zone 1 - 2% sulfides
	End of Hole

E-4 Bearing N 75 W; Dip 75°; 53° (a) 400'; 58° (a) 800'

Footage	Description
0-95	Overburden and Amphibolite
95-98	Mineralized Zone 1% sulfides
98-120	Amphibolite
120-133	Mineralized Zone 1 - % sulfides
133-625	Amphibolite
625-627	Mineralized Zone (0.45% Cu) 15% sulfides
627-631.3	Amphibolite
632.3-633.3	Mineralized Zone (1.02% Cu) 40% sulfides
633.3-1001	Amphibolite
	End of Hole


SIMPLE BOUGUER GRAVITY MAP
OF
NORTH CAROLINA
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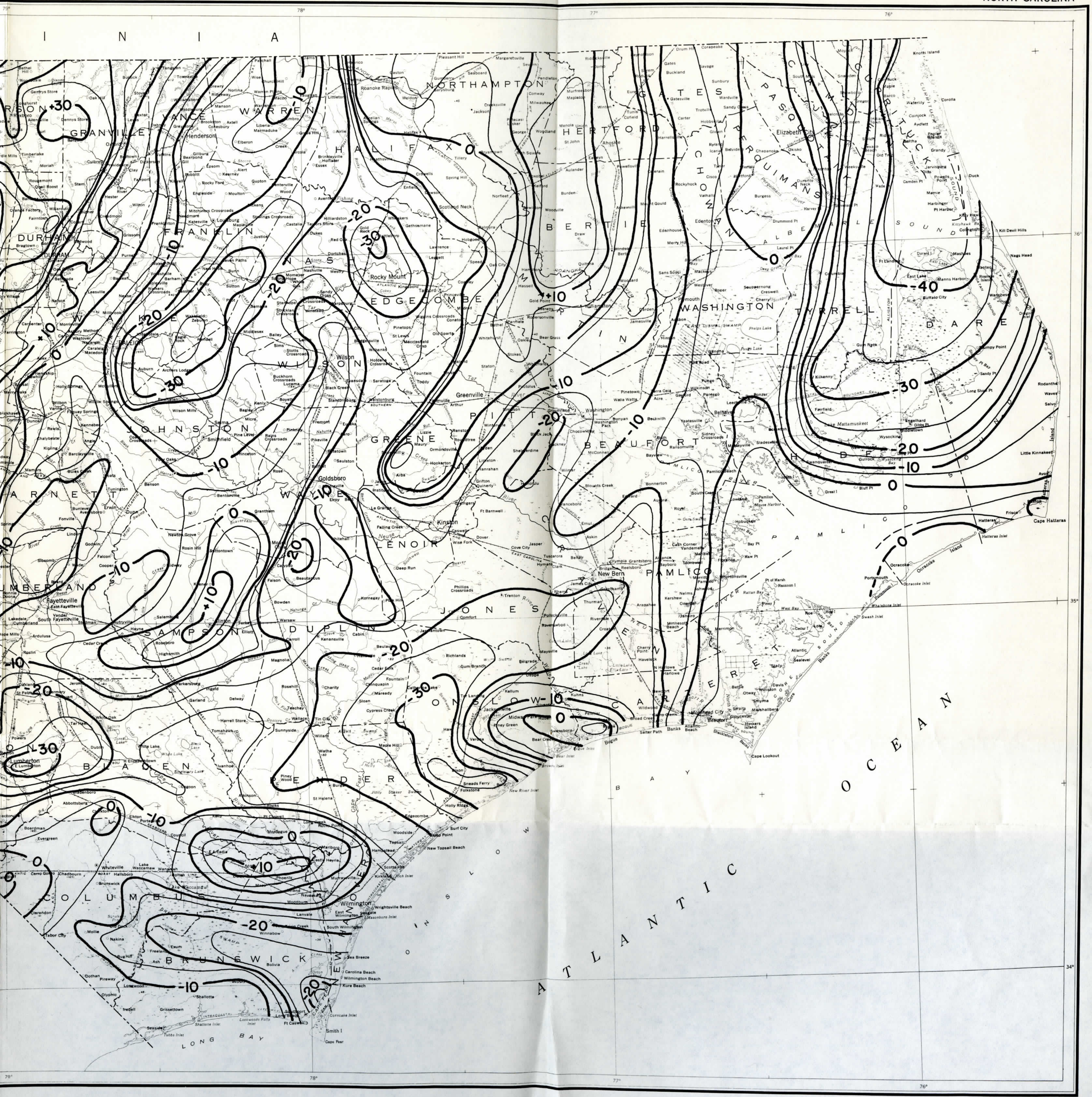

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